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ABSTRACT

The relationship between vision and reading achievement is complex. In this paper, a number of terms relating to vision are defined and some of the limitations of specific measures of vision are discussed. In order to relate vision to reading, it is necessary to segment arbitrarily the continuous process of vision into a series of subsystems, or functions, to allow for quantitative and qualitative discussion. The more important of these subsystems or visual skills are visual acuity, fixation, accommodation, binocular fusion, convergence, stereopsis, field of vision, and form perception. Each of these basic skills is discussed individually. A brief discussion of the interrelationships is provided. (TO)

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VISUAL FACTORS Which Affect Reading Achievement

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VISUAL FACTORS WHICH AFFECT READING ACHIEVEMENT

The relationship between vision and reading achievement is complex. Both vision and reading are in themselves complicated acts, neither of which is easily defined. Both are highly dynamic and involve perceptual, motor, and associative aspects. It is unlikely that two such complex and incompletely understood processes are apt to bear a simple, easily defined relationship.

The thoughts presented in this paper are intended to acquaint the educator with the meaning of the term vision. Only on the basis of full functional investigation of the various aspects outlined here can there be any attempt to relate visual performance with reading achievement.

There is no single over-all index of visual function. In any search for cause and effect relationships between vision and reading one must be careful to define terms and to recognize the limitations of the use of specific measures as criteria for evaluation. It will be the purpose of this paper to analyze vision with regard to providing a basis for relating vision to reading achievement.

Vision is the process by which we learn of the world about us utilizing the information gathered by the eyes. It is necessary to differentiate between the ability to see clearly, or visual acuity, and the over-all process of vision. Unfortunately, the two are frequently erroneously equated and 20/20 visual acuity is interpreted as perfect vision.

Vision is a cognitive act, involving the converting of the raw data of sight into something meaningful. It involves the ability to look at an object and to know what is being seen. It involves determining such things as where the object is, how big it is, what its texture is, how far it is from the observer and from other objects in space, how heavy it is, what its color is, its rate and direction of movement, and all else which can be determined by visual inspection. This involves far more than merely seeing a sharp outline. This involves the integration of visual cues with data from hearing, smell, taste, touch, kinesthesia, proprioception, and all of the other sensory information available, as well as language and previous experience.

This is a slowly developed, ever-expanding process, dependent upon highly elaborate integrative, motor control, and memory factors for its fulfillment. Visual acuity, as measured by the ability to read letters on a Snellen Test Chart, is but one factor of many involved in vision as an information gathering process.

Certainly the ability to see clearly is necessary for reading achievement. The resolving power of the eye must be sufficient to allow for the seeing of the print we read. It need not, however, be the arbitrary 20/20. Indeed, some studies indicate that 20/20 or better acuity is found more often among poor readers than among good readers.

In order to begin to relate vision to reading, it becomes necessary to somewhat arbitrarily segment the continuous process of vision into a series of subsystems or functions to allow for quantitative and qualitative investigation. Visual acuity would be one of these classifications. The more important of the visual skills are as follows:

1) VISUAL ACUITY
   The ability to see small objects clearly.

2) FIXATION
   The ability to accurately aim the eye. Although the human eye can see over a large area at once, it is capable of clear vision only over a limited area of approximately 1½ degrees. This places a premium on the ability to fixate accurately.

   Fixation is generally considered in three aspects.

   a) Direct fixation
      The ability to aim at a stationary object.
   b) Pursuit fixation
      The ability to follow a moving object with the eyes.
   c) Saccadic fixation
      The ability to shift rapidly from one object to another.

3) ACCOMMODATION
   The ability to adjust the focus of the eye as the distance from the object varies (such as shifting back and forth between book and blackboard.)

4) BINOCULAR FUSION
   The ability to simultaneously integrate the data from the two eyes to form a single percept. The condition known as suppression occurs when one eye is ignored.

5) CONVERGENCE
   The ability to turn the two eyes toward each other to look at a close object.

6) STEREOPSIS
   A fine degree of relative depth discrimination possible only when there is good binocular fusion.

7) FIELD OF VISION

The area over which vision is possible. This includes the central portion where fine form discrimination is possible and the periphery which is less sensitive to form vision, but more sensitive to motion and to low levels of illumination.

8) FORM PERCEPTION

The ability to organize and recognize visual sensations as shapes.

These basic skills are reviewed one at a time.

VISUAL ACUITY is a function of the eye itself and of the conducting pathways to the brain. At this point it might be well to note that there is no actual vision at the eye itself. The eye acts as a collecting device which responds photochemically when light strikes it. This photochemical reaction triggers a portion of the millions of nerves which go from eye to brain. The electrochemical transmissions along the nerves have no aspect of vision until they reach that portion of the brain which can interpret them as sight or vision.

The eye may be considered as the television antenna, the nerves as the antenna wire, and the brain as the television set. There is no picture in the antenna or wire. Only when the television set unscrambles or decodes the electrical signals in the wire is a picture possible.

Most people are capable of 20/20 visual acuity, which means they can read a letter 11/32 inches high when standing twenty feet away. If they cannot identify a Snellen letter (Snellen letters are a particular shape type-face used on standard test charts) of this size, but can recognize one twice as large, then visual acuity is recorded as 20/40. They recognize a letter at twenty feet which theoretically should be seen at forty feet.

In certain cases, there are distortions of the optical system of the eye which prevent clear imagery. Myopia, or nearsightedness is the most commonly encountered. In this type of problem, corrective lenses are utilized to change the light entering the eye to again allow clear sight. In some instances, the eyesight is corrected to 20/20. In other instances, for other considerations, the eyesight is improved sufficiently to allow normal functioning, although not necessarily to 20/20.

Optical distortions, such as myopia, are known as refractive errors. Other refractive errors are hyperopia (farsightedness) and astigmatism. These latter two do not always have the effect of blurring vision,

although at times they may do so. In the case of hyperopia in children, it is sometimes possible for the eye itself to overcome the optical error by adjusting the focus, or accommodative mechanism. If the hyperopia is small, and the person young, this can often be done with little or no effort and little consequence.

If, on the other hand, the hyperopia is high, the effort of adjusting focus may be so great as to fail on occasion, producing intermittent blurring, or may be achieved only with such great effort as to produce headache and other discomfort symptoms. Since the ability to change focus declines with age, most hyperopic people reach a point where the error of refraction actually causes blurred vision similar to that of myopia. Lenses can be used to correct this condition or to relieve the strain of maintaining clear vision.

There are situations, however, where glasses must be prescribed for children with low hyperopia because they cannot easily maintain proper focus for reading. In such cases, there may not be any blurring or discomfort symptoms, but rather a decline in reading efficiency or an avoidance of close work. Relatively weak prescriptions can be of great value in such instances, particularly in the case of young children who have not mastered full control of their focusing mechanism.

Astigmatism is a refractive condition whereby elements of the eye's optical system are irregular. Dependent upon type, magnitude, and age, its effects can be quite different. At times it is responsible for blur, at other times discomfort, and frequently both. In general, the effects of astigmatism tend to resemble that of hyperopia, only to a greater degree in the case of small distortions. Astigmatism is usually present in conjunction with either myopia or hyperopia. It too, may be corrected by glasses to restore satisfactory visual acuity and/or relieve symptoms.

A fourth condition, while not a refractive error in the strict sense of the word, should be mentioned at this point. The ability to accommodate or adjust the focus of the eye is normally a function of age, reaching its peak in adolescence and then declining steadily. At about age forty, this ability is generally so depleted as to make changing focus from far to near difficult or impossible. This is known as presbyopia.

Dependent upon the fundamental refractive conditions, presbyopia will have different ages of onset, and present different symptoms. In general hyperopic people, since they often use their accommodation to maintain clear distance vision, are bothered by this failing sooner than others. One symptom is generally

a blurring of print at reading. For this reason, and since the corrective lenses are similar to those used for hyperopia, presbyopia is frequently erroneously called far-sightedness. Everybody becomes presbyopic as they grow older. Nearsighted people may find that the glasses which provide clear distance vision are unsatisfactory for close work, and that they need weaker glasses or no glasses for reading.

Aniseikonia is another correlation which, while not strictly a refractive error, should be mentioned. Sometimes the perceived images of the two eyes are not identical in size and/or shape. This occurs most often when the two eyes have dissimilar refractive errors. The lenses which correct for myopia, for instance, tend to reduce the perceived size of objects while the lenses used to correct for hyperopia have an opposite effect.

If the image size difference between right and left eye is large, it becomes difficult for the individual to integrate the eyes. Severe discomfort symptoms or distortions in space perception can result. Special corrective lenses are required to correct aniseikonia.

FIXATION ability is the second of the most basic of the visual skills. Direct fixation is generally possible in a sound, healthy eye with refractive error adequately corrected. When we consider pursuit fixation, or the ability to follow a moving object with the eye, the problem becomes a highly complex one. This is not a simple innate act but is rather the product of slow and laborious learning beginning in infancy.

If a person attempts to look directly at a small moving object, the image of that object will not continue to fall upon the central area, the fovea, unless the eye is turned to keep the image centered. Just how is this accomplished? What controls the rate and direction of eye movement necessary to maintain accurate fixation?

As the image moves off the center or fovea, it lights up other areas of the retina (or light sensitive layer of the eye.) Each area, as it is stimulated, sends a signal to the brain. When a sufficient number of signals have reached the brain, a complex mathematical problem can then be solved to give the direction and rate of movement of the object.

Once having determined this, it is necessary that this information be sent to another area of the brain to be translated into nerve impulses to the muscles which actually move the eye. This, too, presents a complicated control problem, since there are six muscles responsible for moving each eye. These muscles sur-

round the eye in a most intricate fashion, and are each of quite different diameter, length and strength. To further complicate matters, their relative mechanical effectiveness varies as the eye is turned into different directions of gaze. To still further complicate the situation, the eye does not rotate nicely about a fixed pivot point, but actually moves slightly sideways and forward and back as it rotates.

The process of vision operates like a computer in order to control eye movements. The retina acts as the radar antenna to collect signals which are transmitted by the optic nerve to the brain which functions as a computer to determine the pathway of the moving object. The brain must also compute the necessary muscle actions required to move the eye appropriately to keep the object in direct view.

To facilitate this control over eye movement, the brain area devoted to control the eye movements is fully as great as the brain area devoted to control all of the rest of the voluntary muscles of the body combined. Each eye, by itself, is capable of sending as much sensory data to the brain as the rest of the sensory mechanisms of the body combined. A full two-thirds of all sensory information is visual.

It is estimated, that in the matter of pursuit fixation, the time allowable for the entire process of sending signals to brain, decoding and computing them, translating them to action signals to muscles, and execution of the motor movement of the eye to remain on target as the object moves, is altogether two-fifths of a second. If there is a delay in any phase, the observer will not be able to follow accurately with his eye.

Saccadic fixation, or the ability to shift the eye rapidly from looking directly at one object to another object, is perhaps even more complex than pursuit fixation. This involves shifting attention from that which is being looked at, to some peripheral, blurred point off to a side. Then there must be a calculating in advance of the precise angle of rotation required, and also of the precise signal strength to each of the six extra-ocular muscles.

Here again, the analogy of the radar-like scanning mechanism and brain-computer serves to illustrate the type of control involved. More so than in the case of pursuit fixation, another aspect of the process becomes important. That is the ability to pre-compute and store data and motor patterns. This is especially so in view of the previously mentioned fact that the extra-ocular muscles change their relative effectiveness in different directions of movement. Hence a 15 degree turn to the right will involve an entirely

different set of muscle actions dependent upon whether the movement starts from a point directly ahead, or if it starts with the eye initially aiming slightly to one side.

The complexity of oculo-motor control cannot be over-emphasized. It is no surprise to discover that, in the normal course of events, many children do not develop sufficient control over eye movements to make the delicate pursuit and saccadic fixation movements required of reading until they are six or seven years of age.

The third basic skill to be discussed, ACCOMMODATION, the ability to shift the focus of the eye to adjust for varying viewing distances, is another complicated visual skill. There is a plastic-like lens and muscle system within the eye which is responsible for this facet of visual control. As mentioned earlier, this control mechanism reaches its peak in adolescence and then, due to a loss of muscle tone and an actual hardening of the substance of the lens itself, declines for the remainder of life.

Although most children are capable of a large total amount (amplitude) of change of focus, fine control is not easily mastered. The actual control mechanism is not fully understood. In some manner the blur of the optical image triggers the corrective focus change, but when operating properly, the focus change is so rapid as to be unknown to the person. This accommodative mechanism is under the control of the involuntary nervous system.

Although there is no direct voluntary control over the accommodative mechanism, the focus changing of the eye is very closely coordinated with other aspects of vision that are under voluntary control. As such, minor distortions in focus facility can often be the cause of a great deal of discomfort and visual inefficiency.

Since the involuntary nervous system as a whole is responsive to endocrine and emotional changes in the person, the accommodative system cannot be analyzed solely in terms of optics. Although physically capable, school age children characteristically do not precisely adjust their focus for print held at a normal reading distance but rather under or over-focus for the optical distances involved. This lack of precise focus is caused, among many other factors, by the difficulty, content, and interest in the text of the matter being read. Non-optical factors can greatly influence the operation of the accommodative mechanism.

In general, the accommodative mechanism or focus is considered to be at rest when viewing distant objects. This is strictly true only for myopes, and emmetropes (people who are not myopic, hyperopic, or astigmatic). Young hyperopes tend to utilize accommodation to overcome the error of refraction to maintain clear vision. A fully corrected hyperope or astigmat, whose spectacle lenses obviate the need for accommodation, could also be considered as having relaxed accommodation for distance seeing.

At any attempt to look at closer objects, there has to be a shifting of the focus to maintain clear vision. Since the greatest part of learning takes place at close distances, and since reading is essentially a near centered task, it is necessary that this visual skill be operating easily and with fluidity. It might be noted in passing at this point that the accommodative function cannot be evaluated if the examination is done under cycloplegic medication. Such medications temporarily paralyze the focus mechanism and hence permit no measurement of its functional abilities.

BINOCULAR FUSION, the fourth basic skill, is the ability to simultaneously integrate the data from the two eyes to form a single percept. This is a highly elaborate skill, since there are no physical connections between right and left eyes. The eyes are separate in the head, each in its own eye socket, and each surrounded by its own set of six extra-ocular muscles. Each eye has a separate optic nerve which sends information from the eye back up to the brain. There is no connection of any sort between right and left eyes until the optic nerves reach the brain.

Coordinating and aligning the eyes presents a monumental control job for the brain. The data from the two eyes must be almost identical before the brain can fuse the two "pictures" into a single image. This means that the eyes must be physically aligned with an exceedingly high degree of precision. If there is even a slight misalignment, diplopia or double vision will result. In this situation, the vision of one eye is frequently suppressed or actively inhibited, in order to avoid confusion.

This very important phase of this binocular fusion process needs singling out as a special visual skill. CONVERGENCE is the term applied to the act of turning the two eyes toward another when looking at a near object. For viewing an object at a distance the eyes remain parallel to one another. If the object of regard is moved, the eyes move symmetrically as a team to follow it. If, however, the object of regard is brought close to the eyes, then parallel alignment

will no longer allow single binocular vision. Then both eyes must turn toward the nose, or converge. If convergence cannot be done accurately and sustained easily, it becomes impossible to maintain binocular fusion. The resulting diplopia or suppression can be quite handicapping.

It is also necessary that convergence be closely coordinated with accommodation, in order to maintain binocular single and clear vision. As attention is shifted from one point to another, there must be precise shifting of both the alignment of the eyes and the focus of the eyes. This relationship is known as the accommodative-convergence relationship and since accommodation is a function of the involuntary nervous system, and convergence is under control of the voluntary nervous system, this is no easy task. Actually this is a learned association between two aspects of visual function which takes years of practice to be achieved efficiently.

STEREOPSIS, the sixth visual skill to be discussed, refers to a very fine type depth discrimination which is possible when the two eyes are satisfactorily yoked as a team. This aspect of distance judgment is a function of binocular vision and cannot be achieved unless there is good fusion. Stereopsis allows a critical judgment of relative distance of two objects.

Stereopsis should not be confused with distance judgment or depth perception per se. It is possible for even a one-eyed individual to judge distance by making use of many visual cues independent of binocular fusion cues. Interposition, relative size, clarity, perspective and many other learned relationships between vision data and other experiences can serve to allow judgment of distance.

Stereopsis refers to the critical distance judgments required when other cues are not available or inadequate. Because of the separation of the eyes each eye sees a slightly different view of the scene. The brain can reconstruct this into a single, solid percept, making possible very fine depth discriminations. Poor stereopsis is an indication of incomplete binocular fusion.

FIELD OF VISION is the next visual skill to be considered. Earlier it was stated that the human eye can see clearly over a limited central area. However, despite this limit over the range of clear vision, the eye is actually capable of seeing a vast panoramic area at one time. With the two eyes held steady, it is possible for the view to encompass approximately two hundred degrees laterally and one hundred thirty-five degrees vertically. This is known as the field of view which includes both central and peripheral areas.

For the most part, the peripheral field is not greatly sensitive to discerning shape and hence off-center visual acuity is very poor (regardless of the presence or absence of refractive error). The left and right peripheral fields, ("side" vision) are, however, very sensitive to movement and function well in dim illumination. There is a great interplay between central and peripheral vision, with the periphery acting as a scanning and steering mechanism to enable accurate direct fixation. An object is located peripherally and then the eye moves to permit more detailed inspection.

FORM PERCEPTION, the last visual skill listed above, is the ability to recognize shapes. This is perhaps the most important of all the skills in relation to learning to read. Visual acuity refers to the ability to see the lines of the Snellen Chart E as separate and distinct lines. Form perception is the ability to organize those lines into the concept of an E. This is not a completely innate process and involves learning. The next paragraphs consider the achievement of form perception from a developmental point of view.

Throughout this discussion the concept that various aspects of vision such as control of extra-ocular muscles, accommodation, convergence, fixation, and binocular fusion involve learning has been emphasized. The integration of hearing, smell, taste, proprioception, kinesthesia, touch, and all of the other sensory information available to the human, as well as memory and language with the information collected by the eye from the light falling on it is the key to this learning.

At birth, vision is not the dominant sense. Although the entire physical mechanism necessary for vision is present at a very early age, the infant does not operate satisfactorily on the basis of visual cues. Initially internal visceral stimuli, touch, kinesthesia, and proprioception seem to be more useful to the child. Gradually, by a process of trial and error comparison, the child learns that what he sees and what he touches are the same thing. When this matching of information becomes well established, and only then, the infant can make independent use of vision by allowing visual data to trigger the memory of previous, more concrete, tactual understanding of the thing being seen. Vision may be considered as an extension of touch to allow contact with the world beyond the physical limits of the body.

Bit by bit, the child builds a visual world, by integration of visual information with information from other senses and from the memory of previous experiences. Along with this development of accurate

interpretation of the data of sight, there is a refinement in the muscular control necessary to operate the elaborate mechanism of vision. Slowly a higher degree of precision of fixation, accommodation, and convergence develops.

With practice and experience, the task of accurately aiming eyes becomes less arduous and more accurate. Initially, the child needs the data of touch to assist in the mental computation of where and how to move eyes to look at a particular object. With experience, the support of bodily contact can gradually be withdrawn. Initially children go through a stage of hands leading eyes, which gradually gives way to the adult pattern of eyes leading hands. This is a slow transition, generally not completed until age six, seven, or eight.

Similar patterns of development take place with all of the sub-systems of vision. Vision becomes the dominant process in human behavior only after years of practice and development.

This development can be traced in the case of form perception as a visual skill. The first concept of boundaries or contours in the perceptual world is on the basis of proprioceptive or kinesthetic cues. When an infant is physically blocked from further movement by a wall, or if his arm movement is restricted by the side of the crib, he becomes aware of the discontinuity of the milieu surrounding him. From an awareness of boundary, the child learns an awareness of shape on the basis of the feel of moving his body or part of his body around the borders of the shape. Tactual shape is more meaningful than visual shape at an early stage in child development. As the child develops, he is able to substitute eye movement around a contour in place of actual overt body or hand movement. Thus eye movement proprioception serves to recall bodily movement, which in turn recalls the feel and shape of the object being viewed. In the more sophisticated child, there is no longer a need for overt eye movements around the contour and the process of recollection and matching to previous experience takes place instantaneously.

The rapidity of this recall process in the adult has led to the misconception that the organization of visual data into shape is completely inborn. This is not so. Visual form perception is a product of the learned association of visual sensory data with practiced eye movement skills, bodily movement patterns, and previous experience. It is a derived visual skill requiring years of experience and practice at increasing levels of complexity for its fulfillment. Frequently, young-

sters enter first grade with visual perception skills so inadequately developed that growth in reading skill is seriously slowed or inhibited altogether.

It becomes very apparent that the various aspects of vision as outlined above tend to overlap and are mutually dependent one upon the other. Vision is a continuous process and as such doesn't allow for clear-cut segmentation. For example, fixation cannot be considered without appreciation of the concept of a visual field of view as the basis for the control information to allow for steering of the eye. Binocular fusion, convergence, stereopsis are all concerned with aspects of the teaming of the eyes. Accommodation must be considered as it relates to convergence, and so on.

When one considers the interdependence and interaction of the various visual abilities, the task of relating vision to reading becomes enormous. Classification of vision into eight factors is, at best, quite arbitrary. The vision skills are completely intertwined with one another and also with other sensory and motor systems. A deficiency or lack of proper development in any aspect may modify the entire complex.

The preceding paragraphs have been written to give insight into the complicated process of vision in order to permit relating vision with reading achievement. Vision has been defined as an information gathering process involving integration of the data of sight with other sensory-motor information to permit understanding of what is seen.

Eight vision skills have been described. The operation of each has been explained, as well as the inter-relationships among the various vision skills. The development of some of these vision skills has been outlined.

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